THE PREDATION OF SLUGS BY THE NEW ZEALAND FLATWORM, *ARTHURDENDYUS TRIANGULATUS* (DENDY) (TERRICOLA: GEOPLANIDAE)

PETER H. GIBSON AND DEREK J. COSENS

Institute for Cell, Animal and Population Biology, University of Edinburgh, Ashworth Laboratories, West Mains Road, Edinburgh EH9 3JT, UK.
E-mail address: peter.gibson@ed.ac.uk

ABSTRACT

The presence of *Arthurdendyus triangulatus* (Dendy) on the soil surface under rubber matting in an area of waste-land in Edinburgh was regularly monitored over four years. During February and March 2001 three chance observations were made of specimens of the flatworm attacking the slug *Arion fasciatus* (Nilsson). In a field study in four Edinburgh allotments from February to April 1993 using artificial soil surface shelters dead earthworms were found but no dead slugs. In laboratory container experiments during the same period, specimens of the slug were eaten but not in preference to earthworms. These studies suggest that slugs may contribute to the diet of *A. triangulatus* in the field when earthworms are scarce and this could reduce the vulnerability of earthworms.

INTRODUCTION

The New Zealand flatworm *Arthurdendyus triangulatus* (Dendy) (Terricola: Geoplanidae), until recently known as *Artioposthia triangulata* (Dendy) (Jones & Gerard, 1999), is a predator of earthworms and is commonly found in urban areas of Scotland following its introduction some forty years ago (reviewed by Cannon *et al.*, 1999). The species is of interest because of its potential effect on agriculture, especially organic farming, due to a possible reduction in soil fertility following a decline in earthworm numbers. In the present study the observation that *A. triangulatus* feeds upon slugs in addition to earthworms is investigated.

MATERIALS AND METHODS

Waste-land study

Observations on the fauna under a piece of discarded black rubber matting were made at fortnightly intervals over four years from March 1998. The matting was 1 m^2 in area and 10 mm thick, and lay on bare soil in a piece of waste-land at Craighouse in Edinburgh, Scotland (Ordnance Survey grid reference NT 273608). The waste-land had previously been a car park constructed from granite hard-core, which had over the years accumulated soil to a depth of 40 mm.

Allotment study

The numbers of *A. triangulatus*, earthworms and slugs were monitored between February and April 1993 in four similar allotments in Edinburgh: Lady Road (NT 275714), Mortonhall Road (NT 257711), Midmar Drive (NT 251706) and West Mains Road (NT 263710). These allotments have been intensively studied over a number of years (Gibson & Cosens, 2000a & b). Experimental shelters were used, each made from a 40 × 35 cm plastic bag filled with 10 kg of soil and placed inside a

Table 1. Four laboratory studies on the feeding of *Arthurdendyus triangulatus* when presented with *Dendrodrilus rubidus*, *Arion fasciatus* and fresh minced beef for up to 31 days

Treatment (*n*)	Mean weight of flatworm (g)		Mean weight of "prey" (g)	Survival (days)
	Start	Finish		
1. Earthworm trial (9)	0.91±0.23	1.06±0.21	0.22±0.02	4.22±0.70
2. Slug trial* (2)	0.90±0.17	1.11±0.25	0.59±0.09	2.50±1.06
Slug trial* (6)	0.74±0.14	0.64±0.12	0.84±0.10	31
3. Minced beef trial (9)	0.71±0.10	0.60±0.11	1.44±0.38	31
4. Earthworm and slug trial** (18)	0.77±0.08	0.86±0.09	0.24±0.02	4.33±0.56

*Nine specimens of *A. triangulatus* were used at the start of this study but one died.
**18 specimens of the slug were not eaten in 31 days.

second identical bag, which was then stapled closed. A total of 104 shelters were placed on the ground in close contact with the soil after clearing away grass and other vegetation, and each had a soil contact area of 0.14 m^2. The shelters were placed equidistant from each other in staggered rows in each of eight fallow 200 m^2 plots, two in each allotment. The shelters within the rows and the rows themselves were 4 m apart. Because of the time required, the shelters were laid over 7 days starting on 16 February and ending on 22 February 1993. The numbers of *A. triangulatus*, live and clearly dead earthworms (they showed no movement), and slugs under the shelters were recorded every two to five days over 45 days. Observations began after each shelter had lain in position for 20 days, and therefore started on 8 March through to 14 March. Consequently observations were terminated from 22 April through to 28 April 1993.

Laboratory study

Specimens of *A. triangulatus*, the earthworm *Dendrodrilus rubidus* (Savigny) and slug *Arion fasciatus* (Nilsson), were collected in February 1993 from under wooden planks, plastic sheeting and paving stones lying on bare soil within the four allotments. The study was carried out over 31 days using screw-topped one litre glass containers which were one-quarter filled with damp soil from one of the allotments and which had first been sieved using a 5 mm mesh to remove stones. A specimen of *D. rubidus* was added to the first container, a specimen of *A. fasciatus* to the second, minced beef (which was replaced weekly) to the third, and a specimen each of *A. fasciatus* and *D. rubidus* to the fourth. All the specimens were weighed before being put into the containers. Single specimens of *A. triangulatus*, which had been starved for three weeks, were weighed and one was placed in each container. The study was carried out at 10 °C in the dark and the containers examined daily to determine whether any specimens had been eaten. At the end of the study the specimens of the flatworm and the earthworms were reweighed. The first three treatments were replicated nine times and the fourth 18 times.

Results

Waste-land study

Specimens of *A. triangulatus* were first found under the rubber matting in 2000 and subsequently they were found regularly. Earthworms and slugs were also commonly found. On 25 February 2001, two specimens of *A. triangulatus*, each weighing 0.8 g, were found under the matting each in the process of eating a slug, *Arion fasciatus*. The head end of both slugs had been partially digested (5% of the body) and the remains of the slugs weighed 0.3 g and 0.4 g. On 7 March another *A. triangulatus*, weighing 0.8 g, was found eating a slug of the same species. The head had been eaten (5% of the body) and the remains of the body weighed 0.7 g. All three slugs had produced copious mucus.

Allotment study

The mean numbers of specimens per shelter ($n = 104$) found over 45 days were: 21.1 (sum = 2190, SD = 21.9) live earthworms, 0.8 (sum = 70, SD = 2.1) mostly whole but clearly dead earthworms, 30.5 (sum = 3170, SD = 24.0) live slugs, and 5.6 (sum = 583, SD = 6.0) *A. triangulatus*. There was a variety of species of earthworm and slugs. Spearman rank correlation showed that there was a significant positive correlation ($n = 99$, $P < 0.01$) between the numbers of *A. triangulatus* and dead earthworms ($r = 0.408$) and between the numbers of *A. triangulatus* and slugs ($r = 0.287$). There was no significant correlation between *A. triangulatus* and live earthworms. The calculations were made using the mean numbers of specimens per shelter per plot per sample date.

Laboratory study

In the first of the four treatments (Table 1) the specimens of *A. triangulatus* ate all nine individuals of *D. rubidus* within about four days (mean = 4.2 days, SD = 0.70, $n = 9$) and gained a mean of 16.5% in weight. In the second treatment, one of the nine specimens of the flatworm died. Out of the eight *A. fasciatus*, two were eaten on day 1 and day 4 (mean = 2.5 days, SD = 1.06, $n = 2$) and the specimens of *A. triangulatus* gained a mean of 23.3% in weight. The six remaining slugs were not eaten. In the third treatment, the flatworms did not eat any of the fresh minced beef over the 31 days and they lost a mean of 18.3% in weight. In the fourth trial, where 18 pairs of slugs and earthworms were each kept in the same containers with *A. triangulatus*, all the earthworms were eaten. This took about four days (mean = 4.3 days, SD = 0.56, $n = 18$) and the flatworms gained a mean of 11.7% in weight. None of the slugs was eaten.

Discussion

These chance observations of *A. triangulatus* apparently attacking the slug *A. fasciatus* raise the question of whether the flatworms were simply exploring the possibility of slugs as a source of food and whether the flatworms were scavenging dead or injured slugs. No such attacks or scavenging have been reported (Cannon *et al.*, 1999) and no dead or attacked slugs were found during the allotment study carried out at the same time of year. However, *A. triangulatus* was found to attack and eat apparently healthy slugs presented to them in the laboratory. Feeding on the slugs resulted in a gain in weight thus showing that the slugs were of nutritional benefit to the flatworms and were unlikely to be attacked for some other reason. The percentage increase in weight of *A. triangulatus* was, perhaps surprisingly, greater

than that gained from feeding on earthworms. This, again, suggests that slugs are an acceptable source of food. The flatworms did not eat the minced beef presented to them and therefore appeared to be actively seeking the slugs and not simply driven by extreme starvation to scavenge. This suggestion is in keeping with the observation that the flatworms were never seen to eat carrion in the field.

Although *A. triangulatus* ate slugs out of choice they clearly preferred earthworms when these were available as demonstrated in the laboratory choice experiment. This raises the question as to why the flatworm should attack slugs under the rubber matting in the waste-land. The answer would appear to be, as in the laboratory experiment, that it did not have a choice. At the time of the field observations the number of earthworms under the rubber matting would have been small. The reason for this is that the soil layer was so thin (40 mm), and those earthworms that were eaten would have to be replaced by others from outside the car park some three metres away from the matting since they could not have come up through the granite hard-core. *Arthurdendyus triangulatus* may, therefore, have been forced to eat slugs as an alternative to earthworms. This scenario should be compared with the conditions in the allotment. Here the numbers of earthworms for the same time of year was relatively high since the soil depth was not limited in the same way. In the allotment there were many earthworms since large numbers of dead ones were found (the reason for their deaths was not obvious). The correlation between number of dead earthworms (as a measure of the total numbers of earthworms) and *A. triangulatus* in the allotment suggests that earthworms were sufficiently numerous to maintain the flatworm. The lowest grass temperatures recorded over this period (minimum monthly mean over the year was $-0.10\,^{\circ}C$ in March, recorded at The Royal Botanic Gardens in Edinburgh) will have driven many earthworms deeper into the soil in the allotment (Gibson *et al.*, in press) but they would still have been available to *A. triangulatus*. However, under the matting the earthworms had no such escape from falling temperatures (minimum monthly mean over the year was $-3.81\,^{\circ}C$ in February) due to the hard-core preventing their downward movement. That is, they became "sitting prey" to *A. triangulatus* and may have been rapidly removed.

The present findings indicate that under conditions where earthworms are likely to be scarce or absent, slugs are also eaten. This may not significantly alter the predation pressure on earthworms but it could reduce their vulnerability where their numbers have been seriously depleted.

Acknowledgements

The authors wish to thank Derek Barker for his assistance and Maureen Cameron for indispensable help.

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